SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 9): A Literature Review of Safety Warning Countermeasures

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9.0 Program Overview

Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver's state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

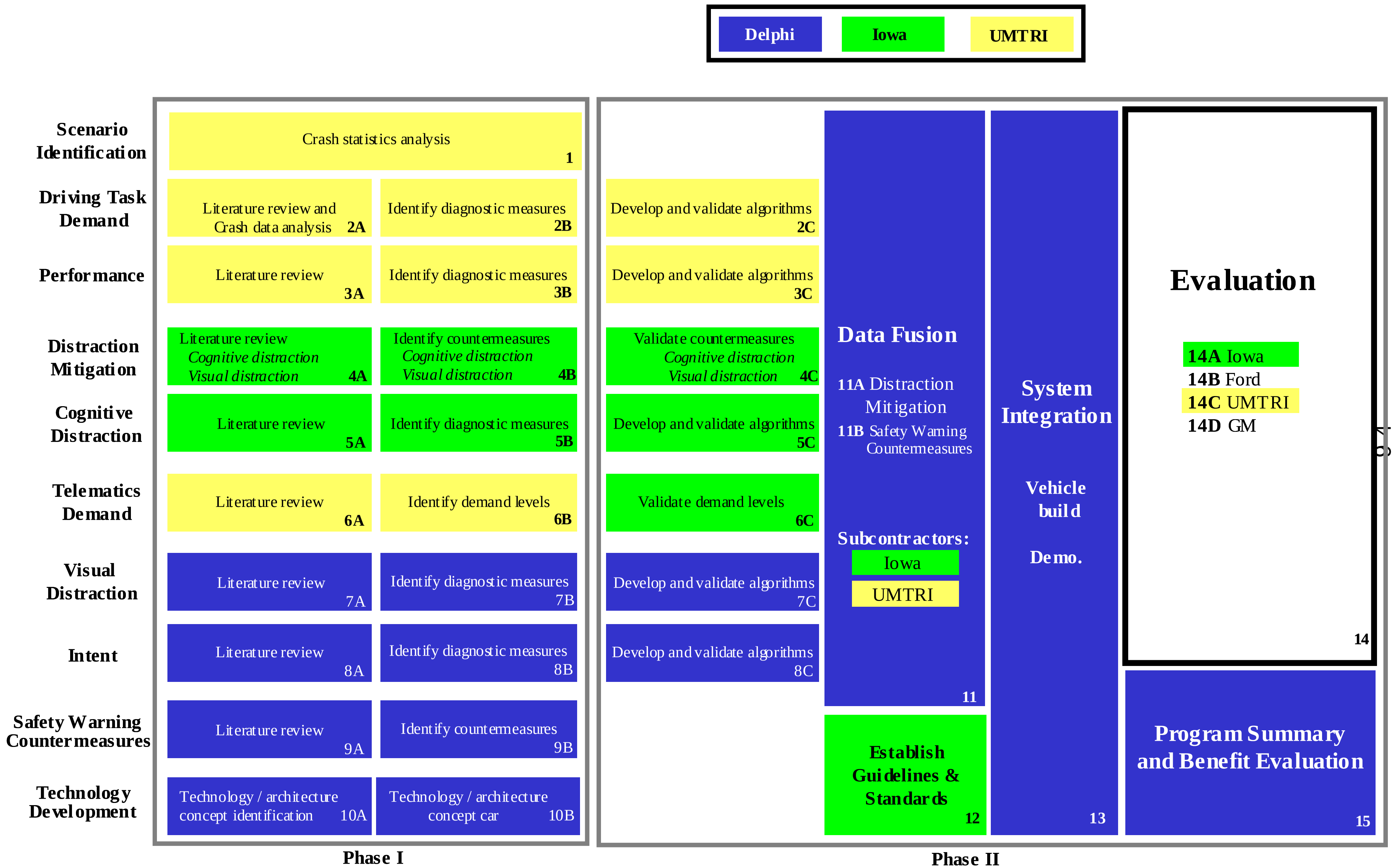

Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems. The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2: Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required. It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task. Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment. Driving

[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

A safety system that mitigates the use of in-vehicle information and entertainment system (telematics) must balance both attention allocated to the driving task that will be assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, “routine” driving may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

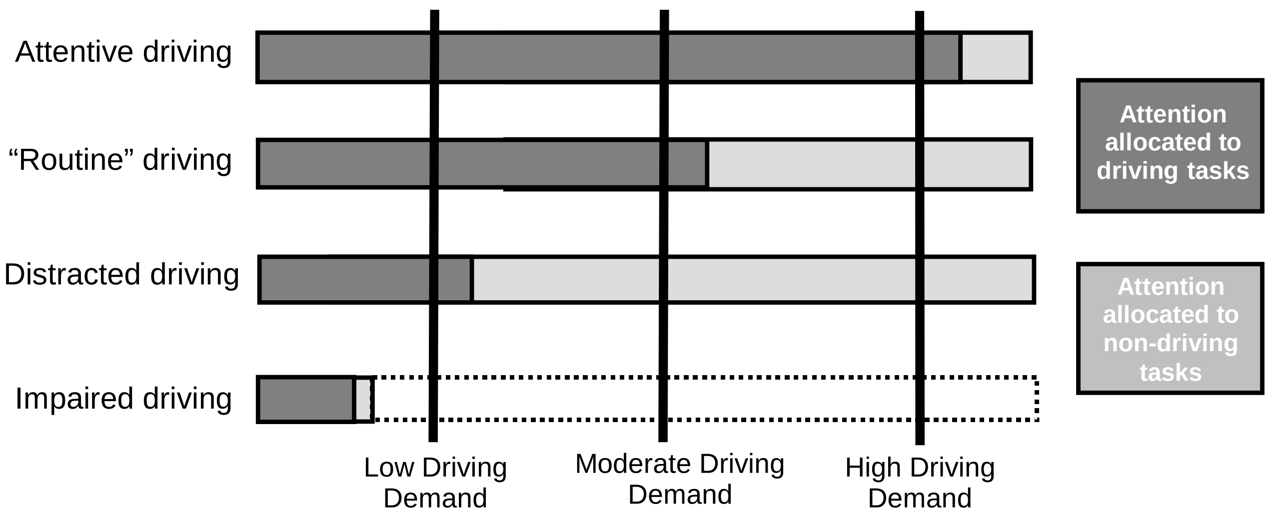

Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is un-precedented and has greatly contributed to program success. A selection of commonalities is described below.

Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I
Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety™ (formerly called GlobalSim™) from Drive Safety Inc., and the same eye tracking system, FaceLab™ from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze measures (e.g., gaze coordinate) are defined in the same manner across tasks.

Common Dependent Variables An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, “ground-truth” dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

Common Driving Scenarios For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

Subject Demographics It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group (35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

Other Commonalities In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

The Content and Structure of the Report

The report submitted herein is a literature review report that documents the research progress to date (March 1--September 10, 2003) in Phase I. During the period of March-September 2003, the effort has been focused on the first Phase I sub-task: Literature Review. In this report, previous experiments are discussed, research findings are reported, and research needs are identified. This literature review report also serves to establish the research strategies of each task.

9.1 INTRODUCTION

The countermeasures of the SAVE-IT program are divided into two major categories. The first set of countermeasures represents the distraction mitigation category. These systems mitigate excessive levels of distraction by adapting the non-driving tasks to be commensurate with the driving task demand. For example, if a driver is traveling along a congested highway and is engaging in a difficult merging maneuver, an incoming cellular phone call could be routed to voicemail. The other major branch of the SAVE-IT program is the adaptive safety warning countermeasures. These systems will adaptively modify safety-warning countermeasures, such as forward collision warning (FCW) or blind-spot warning (BSW) to the instantaneous attention allocation of the driver. For example, if a driver is highly attentive to the forward-visual scene and is not cognitively distracted, an FCW alert could either be delayed or suppressed completely. Conversely, if a driver is highly distracted and not attending to the forward-visual scene, an FCW alert could be initiated much earlier or the driver could be notified if the lead vehicle suddenly begins decelerating. Adaptive enhancements to safety warning countermeasures will serve the dual goals of reducing nuisance alerts and providing earlier warnings when the driver needs it most. Early feedback from the ACAS FOT program appears to reveal that drivers were relatively intolerant of warnings that occurred when they were highly attentive.

The objective of this task is to improve safety-warning systems by designing them to adaptively respond to workload, distraction, and task demand information. During the early stages of this task a set of countermeasures will be identified for further analysis in the SAVE-IT program. The non-adaptive versions of these countermeasures will be developed prior to an evaluation of how these countermeasures can be enhanced using adaptive interface technology. The end product of this task will be a set of adaptive and non-adaptive safety warning countermeasures to be implemented in the second phase of the SAVE-IT program. These countermeasures will be developed further in Task 11B (Data Fusion: Safety Warning Countermeasures) before the System Integration and final Evaluation.

This literature review report will be organized into eight subsections. In Section 9.2 (Introduction) various countermeasure systems will be described and discussed in relation to the relevant collision statistics. Section 9.2 will conclude with a set of recommendations on which countermeasure systems the SAVE-IT program should focus. The next four subsections will describe these countermeasures systems in more detail, including Forward Collision Warning (Section 9.3), Lane Drift Warning (Section 9.4), Intersection Collision Warning (Section 9.5), and Blind-spot Warning (Section 9.6). Section 9.7 will review the literature on adaptive enhancements that have been made to collision-warning systems and describe the potential enhancements that will be investigated further in Task 9 (Safety Warning Countermeasures).

9.2 CRASH CLASSIFICATIONS AND THE ASSOCIATED SAFETY WARNING COUNTERMEASURES

This Section will discuss the breakdown of the police-reported collisions and examine the safety warning countermeasures that have been designed to prevent them. Each subsection of this section will address the four major types of crashes, including rear-end, road-departure, intersection, and lane-change/merge crashes. Because of the limited budget for the SAVE-IT program and due to the fact that some types of crashes are more prevalent or more directly related to driver inattention, recommendations will be made for which types of safety warning countermeasure systems the SAVE-IT task will focus on. Figure 9.1 displays a breakdown of the most prevalent types of crashes based on Najm, Sen, Smith, and Campbell's (2003) analysis of the 2000 GES light-vehicle crashes.

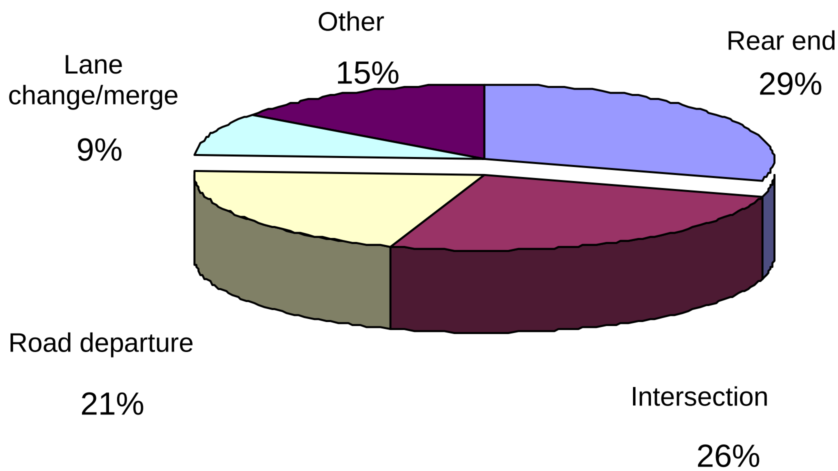

Figure 9.1. *The four most prevalent crash-types of Najm, Sen, Smith, and Campbell's (2003) analysis of the 2000 GES light-vehicle crashes.*

The four categories of rear-end, intersection, road departure, and lane change/merge accounted for a combined 85 percent of all police reported light-vehicle crashes. These four categories also accounted for 58 percent of the 36 thousand collision-related fatalities in 1994 in the United States (based on a report by the U.S. Department of Transportation, 1997). The contribution of each of the four categories to the national fatalities is displayed in Figure 9.2. From this figure it is apparent that road departure collisions produce a disproportionate rate of fatalities compared with the proportion of accidents, indicating that road departure accidents may be more life threatening than the other categories of accidents.

Automotive engineers in conjunction with the U.S. Department of Transportation (DOT) have developed and refined a set of in-vehicle countermeasure systems to mitigate against these collisions. Forward Collision Warning (FCW) systems have been developed to address the problem of rear-end collisions. GM, Delphi, the University of Michigan Transportation Research Institute (UMTRI), and National Highway Transportation Safety Administration (NHTSA) are currently engaged in a field operational test (FOT) to refine and evaluate an FCW and Adaptive Cruise Control (ACC) system. This system uses a forward looking radar to detect the range, range-rate, and azimuth of objects in front of the host vehicle, and warns the driver when there is threat of a rear-end collision. FCW systems are currently available on the market based on either radar- or laser-based sensors.

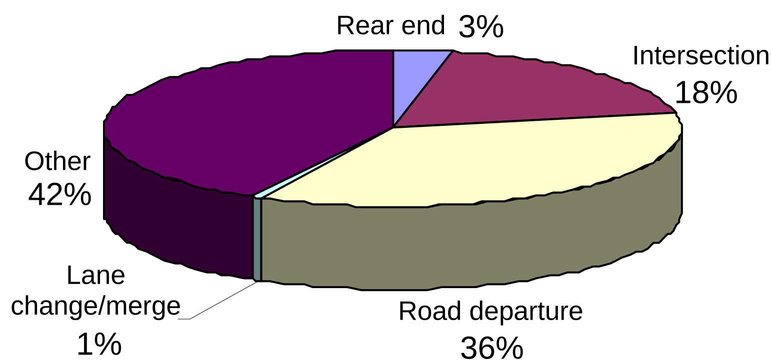

Figure 9.2. *The proportion of 1994 roadway fatalities caused by the four most prevalent types of collisions based on a U.S. Department of Transportation (1997) report.*

Lane Drift Warning (LDW) systems have been developed to address the problem of road departure collisions. LDW systems usually process an image from a forward-looking camera to determine the position of the host vehicle with respect to the roadway. Different systems have been developed to address the problems of lateral drifting on straight roads and road departure during curve negotiation. Whereas the former system warns the driver when the host vehicle begins to drift out of the lane, the latter system warns the driver when the host vehicle has excessive speed for an upcoming turn. Visteon, UMTRI, and NHTSA are currently engaged in a field operational test (FOT) to refine and evaluate a LDW system.

Blind-spot warning (BSW) systems have been developed to address the problem of lane-change/merge collisions. Lane-change/merge collisions are a smaller problem in terms of the number of collisions and fatalities; however, due to their relative simplicity and lower cost, BSW systems are beginning to penetrate the market. BSW systems utilize a side-looking sensor (usually either an ultrasonic-, laser-, or radar-based sensor) that detects the presence of an object in the blind spot of the host vehicle. Although these systems usually only *warn* the driver when the host vehicle is about to change lanes, these systems may *inform* the driver when the blind spot is occupied.

Perhaps the most complex collision problem for designing countermeasures is the problem of intersection collisions. Intersection collisions are multifaceted, comprised of several types of collisions that are quite distinct in terms of the countermeasures designed for their prevention. Intersection collisions are usually classified in terms of the type of intersection (unsignalized versus signalized), the paths of the colliding vehicles, (e.g., straight crossing path [SCP], left turn across path [LTAP], right turn in path [RTIP] etc.), and whether a traffic violation occurred. Many of these distinctions are important for the design of countermeasures and different systems may be required to address the different sub-classes of accidents. As a result of the greater complexity of intersection collisions, safety warning countermeasure systems designed to address this problem are currently at an earlier stage of development than the other countermeasure systems.

This section will discuss the nature of the four most prevalent types of crashes classes, including rear-end crashes (Section 9.2.1), road departure crashes (Section 9.2.2), intersection crashes (Section 9.2.3), and lane change/merge crashes (Section 9.2.4) and the safety warning countermeasures designed to prevent them. This section will be concluded with a summary of the countermeasure systems and a resultant set of recommendations for the SAVE-IT program.

9.2.1 Rear End Crashes

Of the six million police-reported crashes that were reported in the United States for the year 2000 involving at least one light vehicle[2], the single largest category of collisions was rear-end accidents, accounting for 29.4 percent of the total (1.8 million crashes) (Najm, Sen, Smith, & Campbell, 2003). By alerting drivers when they approach a rear-end collision threat, forward collision warning (FCW) systems have been developed in an attempt to reduce the number of rear-end collisions.

Rear-end crashes are frequently divided into the two categories of lead vehicle moving (RELVM) versus lead vehicle stationary (RELVS). RELVS crashes are more common (59.1 percent), however in over half of these cases the lead vehicle had recently decelerated to a stop (Najm et al. 2003). RELVM tend to be more severe than RELVS and are almost twice as likely to involve a fatality (Knipling et al., 1992). In 26.5 percent of cases, the lead vehicle is struck as it is decelerating, compared with 9.5 percent of rear-end collisions, where the struck lead vehicle is traveling at a constant non-zero speed, and 1.1 percent of cases, where the struck lead vehicle is accelerating (Najm et al. 2003). In 2 percent of rear-end crashes the host vehicle is changing lanes when the collision occurs and in 1.6 percent of rear-end crashes the lead vehicle is changing lanes (Najm et al., 2003).

Knipling et al.'s (1992) statistical analysis suggested that over three quarters of rear-end collisions are caused, at least in part, by an inattentive driver. A more recent statistical analysis, based on the 2000 General Estimates System (GES) database, suggests that 65 percent of rear-end collisions involve driver inattention, compared to 13 percent involving speeding, and 6 percent involving alcohol (Campbell, Smith, & Najm, 2003). Although analyses of collision statistics are limited by the ability of agencies to collect accurate information, they appear to suggest that the majority of rear-end crashes occur because the driver is not sufficiently attending to an unfolding event at an inopportune time. When an unexpected event occurs, in front of an inattentive driver, the driver may

[2] This most recent analysis of collision statistics focused on crashes involving at least one light-vehicle. These crashes represent 96 percent of all 6.4 million police-reported collisions.

be too late in detecting the threat. An FCW system may prevent a significant proportion of rear-end collisions by providing vigilance when drivers are inattentive. Knipling et al.'s analysis also reports that following too closely can contribute to accidents (19 percent), suggesting that drivers may benefit from a system that notifies them when they are driving beyond the constraints of their own reaction time.

FCW systems function by predicting the future path of the host vehicle, detecting the presence, location, and motion of objects in the forward coverage zone, and alerting the driver when there is a threat of rear-end collision. The module that is responsible for determining the level of threat is referred to as threat assessment. There are several different threat assessment algorithms that underlie the assessment of threat and these will be discussed in Section 9.3.2. Because the forward-looking sensor is usually unable to classify the type of object that is responsible for the reflection of energy and because the prediction of the future host vehicle path is prone to error, FCW systems can frequently produce nuisance alerts (providing a warning when there is little or no actual threat). In an effort to reduce the rate of nuisance alerts, system designers are often faced with a difficult problem of balancing the system coverage with the nuisance alert rate. With the current state of technology, system designers are forced to reduce the rate of nuisance alerts by tuning the algorithm to be less sensitive in various situations. If the system designers are not careful, the reduction of nuisance alerts may be achieved with too greater cost of system effectiveness. However, adding the assessment of driver state may help to alleviate this problem. When the driver is attentive to the forward visual scene, alerts may be delayed or suppressed. Delaying alerts when the driver is attentive is likely to result in a reduced nuisance alert rate. However, unlike currently available systems, this decrease in nuisance alerts will not necessarily result in a reduction in system coverage. On the contrary, the system could actually be designed to be more sensitive and provide earlier warnings when the driver is not attentive.

The collision statistics demonstrate a substantial connection between driver distraction and rear-end collisions, and therefore the SAVE-IT program is likely to make significant progress by examining the possibilities of providing adaptive enhancement to FCW systems. The details of FCW systems will be discussed in depth in Section 9.3.

9.2.2 Road Departure Crashes

Of the six million police-reported crashes that were reported in the United States for the year 2000 that involved at least one light vehicle[2], over one fifth of the total (approximately 1.3 million crashes) were of the road-departure category (Najm et al., 2003). Najm et al. defined road-departure crashes (2003) as crashes wherein the first harmful event occurs off the roadway. Whereas road departure crashes represent about one fifth of all police reported crashes involving at least one light vehicle, they represent over one third of all crash-related fatalities (U.S. Department of Transportation, 1997). Road departure crashes are therefore quite threatening to the drivers and passengers involved. Mironer and Hendricks (1994) estimated that 21 percent of single vehicle roadway departure (SVRD) crashes were caused by an evasive maneuver and 20 percent were caused by excessive speed.

Mironer and Hendricks attributed 9 percent of SVRD crashes to inattention to lane tracking and 25 percent to driver impairment (including intoxication, sleep, and physical illness, such as seizures). However, a more recent statistical analysis suggests that driver inattention may be involved in 25 to 35 percent of SVRD accidents (Campbell, Smith, and Najm, 2003), whereas drowsy driving may only account for 8 to 10 percent. The collision statistics appear to be quite inconsistent across analyses. If a large percentage of SVRD accidents are attributable to drowsy driving, a drowsy-driver-alerting system that does not necessarily measure the vehicle position on the roadway may provide significant benefit to the SVRD problem. However, to address the more general problem of road departure, two specific systems have been conceived. Pomerleau, Jochem, Thorpe, Batavia, Pape, Hadden, McMillan, Brown, and Everson (1999) referred to the first type of system as a Lane Drift Warning System (LDW). This type of system determines the position of the host vehicle relative to the road, the geometric properties of the upcoming road segment, the vehicle dynamic state, and the driver's intention and warns the driver if it is determined that road departure is likely.

The other type of system, Pomerleau et al. referred to as a Curve Speed Warning System (CSW). This type of system is designed to prevent the SVRD crashes that are caused by drivers losing control of their vehicle due to excessive speed on curved roadway segments. Campbell et al. (2003) estimated that that speeding and loss of control are involved in approximately 25 to 41 percent of SVRD accidents. The CSW system that Pomerleau et al. (1999) developed measures the vehicle position and orientation relative to the upcoming curve, the stability properties of the vehicle, the geometric properties of the upcoming curve, the pavement conditions of the upcoming road, and the driver intentions to determine whether loss of control was likely.

The CSW system is quite complex and requires a relatively sophisticated array of sensors to measure all of the relevant variables (e.g., grade, friction, and banking of the road section). In addition, the crashes that the LDW system are designed to prevent may be more closely related to driver inattention than those that the CSW system is designed to prevent. The application of driver state information is likely to provide considerable benefit to LDW systems, suppressing nuisance alerts when the driver is attentive and perhaps providing earlier warnings when an inattentive driver begins to drift out of the lane.

9.2.3 Intersection Crashes

Collisions at intersections account for approximately one quarter of all police reported light vehicle crashes, with about 1.6 M intersection crashes in the United States annually (Najm et al., 2003). Intersection crashes also represent a significant problem in terms of fatalities, contributing about one fifth of all crash-related fatalities in the United States (U.S. Department of Transportation, 1997). Pierwowicz et al. (2000)

organized intersection crashes using the categories of left-turn across path (LTAP) and straight crossing path (SCP). SCP crashes could occur due to either a traffic violation or an inadequate gap. The crashes were further organized according to the type of intersection control (phased signal, stop sign/flashing red, or yield/other). The percentages associated with the different categories of intersection crashes are organized according to this scheme in Table 9.1.

Table 9.1. Pierwowicz et al.'s (2000) Classification Scheme of Intersection Crashes

	Phased Signal	Stop Sign/Flashing Red	Yield/Other
LTAP	20.7	0	3.1
SCP: Inadequate Gap	0	29.1	1.0
SCP: Violation	23.3	18.2	2.5
Other	2.1	0	0

Note—LTAP represents Left turn across path and SCP represents Straight crossing path.

According to Pierwowicz et al. (2000), 87 percent of the LTAP crashes occurred in the green phase of the traffic signal, where the host vehicle was not required to stop. To design countermeasures to prevent this kind of accident, Pierwowicz developed a system with a wide-azimuth long-range radar system mounted on top of the host vehicle. The threat assessment module of this system calculated whether there was sufficient gap to allow the host vehicle to complete the left turn. This warning system